Q 2: Quantum Networks, Repeaters, and QKD I (joint session Q/QI)

Time: Monday 11:00–13:00 Location: AP-HS

Invited Talk Q 2.1 Mon 11:00 AP-HS

An array of neutral atoms coupled to an optical cavity: A versatile quantum network node — Raphael Benz, Sebastián Alejandro Morales Ramirez, Micha Kappel, Vincent Beguin, Krishna Relekar, and •Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

I will present the plans of a recently established research group in Stuttgart focused on developing multi-qubit quantum network nodes. Our approach leverages an array of tweezer-trapped atomic qubits positioned at the center of a high-finesse optical cavity. All atoms in the array are positioned to ensure strong coupling to the cavity, thus establishing a connection to a photonic quantum channel. I will discuss the prospects of this system as a versatile quantum network node for both quantum computation and communication. Employing the system, a series of experiments is envisioned. I will outline these experiments, including photon-mediated quantum information processing between the intra-cavity atoms, the generation of photonic cluster states, and the generation of optical Gottesman-Kitaev-Preskill qubits. Finally, I will outline the prospects of connecting several atom-cavity systems in a quantum internet architecture.

Q 2.2 Mon 11:30 AP-HS

Quantum network nodes based on neutral atoms in an optical cavity — •Sebastián Alejandro Morales Ramírez, Raphael Benz, Micha Kappel, Vincent Beguin, Krishna Relekar, and Stephan Welte — 5. Physikalisches Institut, Center for Integrated Quantum Science and Technology and CZS Center QPhoton, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany.

The practical implementation of a quantum network is an outstanding challenge that is pursued in several different hardware platforms. Single neutral atoms trapped at the centre of an optical cavity are a promising platform, where many of the required capabilities to build a quantum network were demonstrated. The ability to position and individually control an array of atoms with optical tweezers is a key ingredient for the implementation of multi-qubit quantum network nodes. We will outline the plans of our research group to realize such a setup. Employing the system, a series of experiments is envisioned. We will outline these experiments comprising photon-mediated quantum information processing between the intra-cavity atoms, the generation of photonic cluster states, and the generation of optical Gottesman-Kitaev-Preskill qubits.

Q 2.3 Mon 11:45 AP-HS

Heralded Generation of Atom-Photon Entanglement — •Gianvito Chiarella, Tobias Frank, Pau Farrera, and Gerhard Rempe — Max Planck Institute for Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching bei München

Reducing inefficiencies and infidelity errors in quantum information processes is crucial for the successful implementation of advanced quantum communication and computation protocols. In this work, we introduce a novel method to mitigate such errors during the generation of atom-photon entanglement. The approach utilizes cascaded two-photon emission from a single atom coupled to two crossed optical cavities. The polarization state of one photon is entangled with the spin degree of freedom of the atom, while the emission of a second photon serves as a herald, signaling the successful entanglement generation. This heralding process effectively mitigates inefficiencies and infidelities in the entanglement, and we highlight the potential of our source for quantum communication applications over long distances.

Q 2.4 Mon 12:00 AP-HS

Quantum repeater segment with trapped ^{40}Ca$^+$ ions — •Max Bergerhoff, Pascal Baumgart, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken, Germany

The quantum repeater (QR) segment, as part of a QR link [1], is a fundamental building block for the realization of large-distance quantum networks. By dividing a transmission link into segments and cells it is possible to overcome the exponential loss of direct transmission. Experiments that create atom-atom entanglement with single atoms [2] or single ions in cavities [3] have demonstrated the potential of the atom/ion platform for a QR segment.

We report the implementation of a QR segment with free-space coupled photons from two ^{40}Ca$^+$ ions in the same Paul trap as memories. Atom-photon entanglement is produced [4] by controlled emission of single photons from the ions via excitation with nanosecond laser pulses and separate single-mode fiber coupling. Atom-atom entanglement is then generated by a photonic Bell-state measurement. A full QR link will combine the QR segment with the already demonstrated QR cell [5]; this will require a new ion trap setup with integrated sub-mm cavity, currently under construction.

[1] P. van Loock et al., Adv. Quantum Technol., 3: 1900141 (2020)
[2] T. van Leent et. al., Nature 607, 69-73 (2022)
[3] V. Krutyanskiy et al., Phys. Rev. Lett. 130, 050803 (2023)
[4] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[5] M. Bergerhoff et al., Phys. Rev. A 110, 032603 (2024)

Q 2.5 Mon 12:15 AP-HS

Hong-Ou-Mandel interference of photons generated with nanosecond laser pulses from two co-trapped ^{40}Ca$^+$ ions — •Pascal Baumgart, Max Bergerhoff, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Entangling remote quantum memories is an essential step in the realisation of a quantum repeater segment [1]. It requires the ability to create indistinguishable single photons capable of Hong-Ou-Mandel interference on a beam splitter [2]. When generating single photons by exciting a Raman transition in a single atom, back decays and re-excitations on the driven transition lead to an uncertainty in the photon emission time, degrading their temporal indistinguishability [3]. A common approach that limits the number of back decays is excitation via short laser pulses, in the order of the excited-state lifetime. We present a setup to generate few-nanosecond 393-nm laser pulses to excite the $\mathrm{S}_{1/2} \rightarrow \mathrm{P}_{3/2} \rightarrow \mathrm{D}_{5/2}$ Raman transition in single trapped ^{40}Ca$^+$ ions and create single 854-nm photons. Using two ions in the same trap, we demonstrate Hong-Ou-Mandel interference of the Raman photons. We investigate the dependence of the interference visibility on the pulse length and amplitude, both experimentally and theoretically.

[1] P. van Loock et al., Adv. Quantum Technol., 3: 1900141 (2020)
[2] D. L. Moehring et al., Nature 449, 68-71 (2007)
[3] P. Müller et al., Phys. Rev. A 96, 023861 (2017)

Q 2.6 Mon 12:30 AP-HS

Cavity-enhanced Diamond Color Centers as Quantum Network Nodes — •Yanik Herrmann[1], Julius Fischer[1], Stijn Scheijen[1], Cornelis F. J. Wolfs[1], Julia M. Brevoord[1], Colin Sauerzapf[1], Leonardo G. C. Wienhoven[1], Laurens J. Feije[1], Matteo Pasini[1], Martin Eschen[1,2], Maximilian Ruf[1], Matthew J. Weaver[1], and Ronald Hanson[1] — [1]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands — [2]Netherlands Organisation for Applied Scientific Research (TNO), P.O. Box 155, 2600 AD Delft, The Netherlands

In the realization of quantum networks, efficient interfaces between stationary qubits and optical photons are a key requirement. Diamond color centers are on the forefront of solid state qubits due to their long spin coherence and spin register capabilities in combination with spin-state selective optical transitions. To boost the efficiency of the spin-photon interface, open microcavities can be utilized to Purcell-enhance optical transitions of the color centers. We realized a fiber-based microcavity setup at low-temperature with a high passive stability and microwave integration. This setup is used to Purcell-enhance single Tin-Vacancy centers, demonstrating quantum non-linear effects in the coherent coupling regime. Furthermore, we will present our latest results on implementing a cavity-enhanced quantum network node based on Nitrogen-Vacancy centers.

Q 2.7 Mon 12:45 AP-HS

Towards a quantum repeater with trapped Yb+ ions in an optical cavity — •Santhosh Surendra and Michael Köhl — Physikalisches Institut, Universität Bonn, Bonn, Germany

In a quantum network where entangled photons are used as travelling qubits, a critical challenge is in overcoming the absorption loss of optical fibers. One promising approach is to use *quantum repeaters* to ‘purify’ the state of photons after a certain optical path length by utilizing matter qubits. Such a node is necessary to scale the size of a distributed quantum computer, and quantum communication networks.

We have designed, and are constructing such a repeater node where a sub-millimeter optical cavity can be integrated into a linear Paul trap. Utilization of Purcell effect will allow us efficient extraction, and injection of entangled photons into the fiber-optic network. Furthermore, our system offers independent access to all vibrational modes of ions, enabling us to work directly with the ionic memory qubits. We will share our recent experimental progress, and the challenges we are addressing.